A 1200 VOLT SYSTEM FOR ELGIN AND BELVIDERE, RY.

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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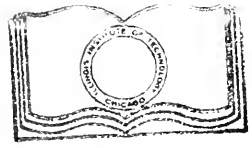

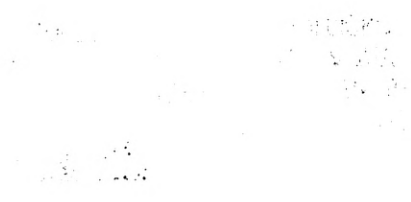

A 1200 VOLT SYSTEM FOR THE ELGIN BELVIDERE RY.

A THESIS

PRESENTED BY

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TO THE

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PREFACE.

The following discussion is divided into two parts, namely one dealing with the present conditions of the Elgin & Belvidere Railway, and the other dealing with the changes that we propose to make.

No description of the actual methods used in the construction of the speed time and current time curves were given, as we assumed that all those who would have occasion to read this are well enough versed in the method of constructing them.

No financial estimate of the reconstruction work planned was made, as we were not in a position to make any accurate estimate, and hence deemed it advisable to eliminate it altogether.

We wish to thank those who have helped us along in this work, especially Mr. Nichols, for his help in the construction of the speed-time curves and the choice of the motor. Also Mr. W. G. Farnsworth of the Arnold Co., who provided us with the profile of the railroad and also with the necessary information regarding it.

Tom C. Bolton

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April 21, 1914.

1200 VOLT SYSTEM FOR
ELGIN BELVIDERE RAILWAY.

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1200 VOLT SYSTEM FOR ELGIN & BELVIDERE RAILWAY.

Route and Connections.

The Elgin & Belvidere Railway extends from Elgin in a northwesterly direction to Belvidere, a distance of thirty six and eight tenths miles. The road connects at Elgin with the Aurora, Elgin & Chicago Railway, also with the trolley line operated by the same company extending to Aurora and connects with other roads to points beyond. At Belvidere connection is made with Rockford interurban railway, operating west from Rockford to Freeport.

The region through which The Elgin & Belvidere Railway and its immediate connections pass is a well settled and prosperous community and offers opportunities for a large passenger and freight traffic. Between the terminal cities of Elgin, which has a population of about 25,000 and Belvidere with 9,000, there are located along the route 9 other cities and villages. The population on and immediately attributary to the Elgin & Belvidere Railway is estimated to be 52,000,

while an additional population of at least 25,000 is made accessable by connecting lines previously mentioned, will provide the company with a passenger traffic bases of about 500,000.

As a matter of fact the passenger traffic has greatly exceeded this estimate, as shown in following table.

	1910	1911	1912
Passengers.	500,905,	525,193,	517,528.
Car Miles.	471,816,	438,434,	470,235.

With the exception of short stretches through several towns, the electric road closely parallels the steam line of Chicago & Northwestern R. R. and occupies an adjacent right of way for greater part of distance.

TRACK CONSTRUCTION.

Except in cities and towns the line is built entirely upon private right of way 50 feet wide. The country traversed is comparatively level and for the most part the grading has been light. A maximum grade of two per cent has been maintained and curves of long radius are used outside of towns. The track has been placed far enough to one side of the center of right of way to allow the construction of two tracks. The standard road bed has a width at grade line of fourteen feet on embankments for single track and a width of twenty seven feet at sidings. In excavation the width of road bed at grade line is eighteen feet for single track and thirty one feet at sidings, this including ditches. The ballast on private right of way is of gravel to a depth of six inches below the ties.

The track is of 70 #T rails 33 feet in length, the joints are staggered and fitted with 4 bolt 22 inch Weber splices. The ties are tamarach hemlock and cedar and are spaced 17 to each 33 foot rail. The rail joints are bonded

with the [illegible] of the [illegible] by [illegible]

[illegible], [illegible] inches long [illegible]

[illegible] capacity. A [illegible] of

[illegible] is [illegible]. The cross [illegible] the

opposite [illegible]. The [illegible] is

formed [illegible] woven [illegible] fencing of the American

[illegible] the standard is

[illegible] inch. [illegible] wires, [illegible]

[illegible] two [illegible] wire at the top. [illegible]

fences are used for cattle guards, and are of

wood construction.

Energy for operation of the line is obtained from the electrical system of Aurora, Elgin & Chicago Railway. The elmhurst sub-station of that road is located 3-1/4 miles south of Elgin and at the point the transmission system of the Elgin & Belvidere road receives the power. The distribution system includes as its principal element a high tension transmission system which carries the three phase alternating current at 26,400 volts to the sub-stations at Gilberts, Union, and Garden Prairie, approximately ten miles apart. At these substations the current is transformed to 600 volts direct and distributed along the trolley wire through the low tension feeders.

The overhead system is arranged with a ground wire; at the extreme top of the pole two upper cross arms carry the high tension wires and the lowest cross arm carries two telephone wires and the low tension feeder. This arrangement while standard is departed from on those parts of the line where the full compliment of

wires as usual is not required.

The standard pole where the bracket arm suspension is used varies between thirty and forty feet in length and is of cypress seven inches in diameter at top, the poles are spaced 100 feet apart and are set seven feet in the ground. They are placed seven feet from the center line of track and are set vertical on straight line while on curves up to three degrees they are given a slight rake in order to draw up to vertical. On sharper curves the poles are braced. The cross arms for the high tension wires are of southern pine 3-½ inches by 5 inches by six feet. The lowest cross arms which carry telephone wires and feeder are 3-¼" by 4-¼" by five feet.

The high tension conductors are three number six copper wires. The wires are transposed to make two complete turns between Garden Prairie and Union, three between Union and Gilberts and two between Gilberts and Clintonville. The insulators which support the high tension wire are

are of brown glazed porcelain Lock No. 408 A Designed for voltage carried and tested for 70,000 volts. They are made in two pieces, cemented together and are eight inches in diameter and seven inches high with a groove for the conductor at the top. As stated before the ground wire consists of No. 6 galvanized wire. It is attached to the pole by a lag screw driven vertically into the apex, being held between washers under the head of the screw. This wire is grounded at every fifth pole by a strip of No. 22 galvanized band iron 3-½ inches wide, which is held at the end beneath the lag screw washer and led down the pole it is securely fastened to the pole by nails and comes to an end at the lower extremity of pole. The ground strip is there riveted to bands of galvanized iron which encircle the base of the pole a few inches apart. All guy wires which extend to within six feet of the ground are connected to the ground wire.

Lightning arresters are installed on every twentieth pole. These lightning arresters are

of a type designed for six hundred volts direct current and are mounted in weatherproof boxes. The ground wire from the arrester is No. 6 B. and S. gauge copper wire, and it is led down the pole along the ground strip and soldered thereto; at the foot of the pole a ground wire passes into the ballast under the track and connects with a No. 0000 cross bond attached to both rails. At the Kishwaukee River and at two other points on the line round plates of one eight inch sheet copper twelve by twenty four in size are buried in the embankment below water level and are connected by No. 0 copper wire to both the ground wire and rails.

SUBSTATIONS.

The three substations along the line have been mentioned. At Gilberts, Garden Prairie and Union the structures provided for this purpose are approximately similar as is shown by plate 21. The main portion of each substation is 29 feet 3 inches by 30 feet five inches, and in the rear is an extension eleven feet eight inches by 25 feet seven inches, extending sixteen feet above the ceiling of the main portion of the building. The high tension wires are brought into the substation from a point directly in front of, at which two poles are set fifteen feet apart with the cross arms turned at an angle of forty five degrees with the usual plane of the arms. From these cross arms the high tension wires pass directly and without other support to insulators fixed on a bracket on the wall of the substation, thence passing through a tubular insulator set into the wall of the substation.

Beyond the tubes the line conductors pass through lightning arresters and are

separated by brick barriers. The main high tension lines pass out of the building in a manner similar to the incoming lines, the arrangement virtually making a loop of the high tension lines in the building. The local lines, which are tapped off from the main conductors in the barriers, pass through lightning arresters, choke coils and oil disconnecting switches.

The lightning arresters are of the General Electric 26,400 volt three phase multiplex type, as are the oil cooled choke coils which have a capacity of 45 K.V.A. The three transformers which are detal connected on both primary and secondary side are each of 110 K.W. capacity and step down the voltage from 26,400 to 370 volts. The three transformers feed into an alternating current rotary panel of the switch board, which is thoroughly equipped to control the rotary.

The three phase 25 cycle rotary convertors are of 300 K.W. capacity designed for 370 volts on the alternating current side. The

direct current voltage is 600. The current for the direct current switch board consists of two feeder panels of 1200 ampere capacity for serving the trolley line. The feeder panels are equipped with 1200 ampere C. C. C. P. type circuit breaker, a "G. I. T." master and a shunt and 1500 ampere single pole single break switch, all of the electrical equipment including rotary converters, switch board transformers, oil switches, choke coils and instruments was furnished by the General Electric Co. and consists of their standard type of apparatus designed for this work. At present one rotary converter is installed in each station, the space being left for an additional equipment, as shown in the ground plan of the substation.

All wiring is done in three inch duct tile imbedded in the concrete floor.

Low tension direct current feeders parallel the entire length of the line, and distributes the current along the trolley wire from the substation. The size of this feeder is 300,000 circular mills. It is supported on locke No. 47 insulators of glazed porcelain, one piece double petticoat and four inches in diameter by three inches in height. At substations an 800,000 circular mill feeder leads the return current from the track into the building. The telephone wires which are carried on the same cross arm are copper No. 12 B & S gauge on locke No. 12 insulator. The telephone wires are transposed at every fifth pole. Telephone jack boxes are provided at frequent intervals, at which the portable instruments carried on the car may be plugged in to afford communication with any part of the system. Located on poles at certain intervals are section tie switches, by which sections of the trolley wire and feeder may be isolated or thrown together at pleasure. These are single pole, quick break

knife switches with auxiliary contacts and terminals. They are mounted on slate bases in weather proof boxes. The covers to the boxes may be locked with switch in either open or closed position.

The bracket arms which support the trolley wires are of the common type of one and one half inch structural steel tubing nine feet in length. Where span suspension,is used, the span wire is five sixteenths inch galvanized strand, two wood strain insulators one inch by nine and one half inches with galvanized malleable fittings are inserted in the span wire, one on each side of the trolley wire. The normal height of the trolley wire is nineteen feet above the top of the rail. The trolley wire is number 000 grooved wire. The feeder wire is tapped into the trolley wire at intervals of one thousand feet. Split "T" clamps are used for this purpose.

ROLLING STOCK.

The rolling equipment of this road includes nine passenger and two baggage and express cars, all built by the St. Louis Car Co. Both ends are vestibuled and the passenger entrance is at the rear only. The interior of the car is divided into two compartments, the main portion being in accordance with standard interrurban practice, having transverse seats of the Walkover pattern. The interior finish of these cars is dark mahogany with a green ceiling decorated in gold, while bronze metal fittings are used throughout. The arrangement of the smoking compartment is somewhat out of the ordinary. The motorman's cab is located at the forward end on the right side, back of the motorman's cab is a sliding baggage door. By dropping three longitudinal folding flat seats, ample space for baggage is provided for when necessary. While the car is intended to run forward under normal conditions, a complete control and air equipment has been provided for in the rear vestibule to allow backward running if necessary. Two trolley poles are also provided

to facilitate running under these conditions.

On the exterior, the car body is painted green with yellow panels, the length over bumpers is forty seven feet one inch, and over vestibules is forty five feet five inches. The width over the outside sheathing is eight feet six inches, and heighth from underside of sills to the top of the roof is nine feet four inches. The truck centers are twenty six feet four inches.

The auxiliary equipment of car includes hot water heaters, sectional parcel racks, pantasote curtains, hand brakes of the St. Louis Car Co. and Ohmer fare registers. The couplers are of the Van Dorn type and pilots are fixed to the trucks in such a position that they do not interfere with coupling two or more cars together.

The interior lighting is furnished by twenty five incandescent lamps and an arc headlight is fitted at the forward end. All wiring is placed in concealed iron conduits.

The trucks are made by the Baldwin Locomotive Co. Rolled steel wheels thirty four and one

half inches in diameter are used. The wheel base is six feet six inches and axles are five and one quarter inches in diameter. The trucks are designed for a minimum radius of curvature of forty five feet, and the speed calculated upon is fifty miles per hour.

Each car is equipped with four G.E.-74 motors rated at sixty five horse power. Type M multiple unit control is used, and air brakes are provided. The weight of car light is sixty one thousand pounds, and with a maximum load of fourteen thousand pounds makes a total weight of seventy five thousand pounds.

The baggage and express cars are double truck like the passenger cars, but are designed for double end operation. The length over the bumpers is forty five feet, and the width over the sheathing is eight feetsix inches. The trucks have thirty three inch wheels and the wheel base is sixty six inches. The maximum speed for which the trucks were designed was thirty miles per hour, and the minimum radius of curvature is thirty five

feet. The motor equipment is the same as that of the passenger cars, except that type K control is used. These cars are heated by stoves. The couplers are the same as those on the passenger cars, and pilots are also attached to the trucks.

The car house and repair shop facilities are located at Marengo.

GENERAL CONDITIONS.

At Elgin and Belvidere waiting stations are jointly maintained by the Elgin & Belvidere Railway and the connecting railways. The schedules have been arranged so as to give patrons close connection with all trains running north, east, and west. By this arrangement what is practically a through service from points north and west of Belvidere to Chicago, and all points on the Aurora, Elgin & Chicago Railway is obtained. An hourly schedule is maintained in both directions. Regular agency stations are maintained at Elgin, Gilberts, Huntley, Union, Marengo, Garden Prairie and Belvidere. Stops are regularly made at these stations and upon signal cars will pick up passengers at any of the principal highway crossings along the line.

CHANGE OF 600 VOLT D. C. SYSTEM.

As stated in part 1, this railroad is now operating at a trolley voltage of 600. We propose to change this for several reasons, to 1200 volts direct current. Some of these reasons are as follows:

1. More economical operating conditions as compared with the 600 volt lines, because of the reduced number of substations, and hence the reduction in the help employed.

2. Higher substation efficiency, by virtue of the fact that it increases the load factor in the substations, because a longer section of the line is fed from one substation and hence power is being drawn from that substation for a longer time than in the case of a 600 volt installation.

3. It is also possible to increase the schedule speed of the trains, but this is of minor importance compared with the first two.

In all, the chief reason for a change in voltage on this railway is that more economical operating conditions will result, and as

profits are the main thing in any railway, we think that we should change the trolley voltage to 1200.

In the building of a new road the saving in substations and feeders is quite an important item, but here, since the road is built, it will not be so important, but as future extensions are possible, they can now be built without the addition of new feeders or substations.

CHOICE OF MOTOR.

In most 1200 volt installations it has been the practice to use two 600 volt motors permanently in series. However, these motors are insulated to withstand 1200 volts, if it should happen to be impressed upon any one of them. The reason for using two six hundred volt motors is obvious, because in some localities, chiefly in cities, it is necessary for the inter-rurban cars to operate at the lower trolley potential of 600 volts, and if the same speed is required it can be obtained by means of a change over switch, which places all four motors in parallel across six hundred volts. However, in some cases, straight 1200 volt motors have been used, and in this case when operating on 600 volt lines the maximum speed is reduced to one half its value on 1200 volts. We followed the usual practice and only considered 600 volt motors.

The motors considered were G.E.-214, G.E.-205, and the Westinghouse 303-A, rated at seventy horse power, one hundred horse power and one hundred fifteen horse power respectively at

600 volts.

It was found that the average length of run was two miles, and the approximate weight per motor, using four motors per car, was ten tons. After due consideration of the profile of the road, it was decided that initial acceleration of one and one half miles per hour per second on the rheostat and a breaking acceleration of two miles per hour per second was the most suitable for this class of service.

With these conditions well in mind and with the aid of the manufacturers bulletin, curves of tractive effort and current consumption as related to speed in miles per hour were drawn for various gear ratios, for each motor under consideration.

Trial runs were then made, consisting of a speed time curve for a distance of two miles on level track. Since the schedule speed of approximately thirty miles per hour was desired, it was necessary for the motors to reach a maximum speed of forty five miles per hour.

On the first trial the G.E.-214 motor

was eliminated, because it could not develop with the minimum gear ratio, the required free running speed.

Our attentions were then placed upon the G.E.-205 motor. It was found that this motor could make the run, but that the free running motor curve with the minimum allowable gear ratio did not rise quite fast enough and though it did finally reach the required value to make the run in the required time, it necessitated a power application covering about two thirds of the total run, and this was prohibited. For this reason it was decided to turn our attentions to a slightly larger motor.

The Westinghouse motor No. 303-A. was the next to be considered. Trial runs were made with the gear ratio as is shown on sheet number 9. It was found that this motor could easily make the run with power applied for only one third of the time of the run. The power consumption was also considered, and it was found for the various gear ratios that there was no great difference in power consumption, and it is necessary for the

ouis to r[illegible] [illegible], and a gear ratio of 2.[illegible] was chosen, with twenty three teeth on the pinion and fifty five on the gear.

With these gear ratios were drawn to show the effect of various girder on the motor, which have been plotted on sheet 10.

ENERGY TO MAKE RUN.

The next to be considered was the profile of the road, which has been placed in this paper as sheets numbers 11, 12, and 13.

Speed time and current time curves were then drawn, as sheets 14 and 15 will show. This was done for the determination of the time required and also the current necessary to make the run. The speed time curves were drawn with the assumption that stops of fifteen seconds duration would be made at all principal highways and towns. From these curves the possible running time was obtained. Then the required time to make the run with the minimum amount of layovers at terminals, giving hourly service with the least number of cars was determined, so the cars could pass where the turn outs are at present located.

The time was found to be one hour and twenty minutes, thus allowing cars to leave Belvidere on the even hour and Elgin on the half hour. The cars now in use were found to be of sufficient size to handle the traffic on the road under these

conditions.

A train sheet was then drawn which shows the position of all trains throughout the running hours of the day. This is shown as number 16. It was then possible to complete the accompanying schedules 20 and 21.

The current time curves were drawn so as to predetermine the energy necessary to propel a car over the line. It was found that an energy consumption of 77.4 W.H. per T.M. was required to make the east bound run, and 76.9 W.H. per T.M. was needed to make the west bound run. From these the load curves were obtained, assuming that twenty amperes were consumed by the dynamotor, and air compressor, the lights being fed from the dynamotor while operating at 1200 volts. The load curve was drawn in three parts, the first part showing the variation of load from 5:20 A.M. to 7:00 A.M. The second part showing the variation of the load during every hour from 7:00 A.M. to 11:00 P.M., and the third part from 11:00 P.M. to 12:25 A.M. These are numbered 17, 18, and 19.

CONCLUSIONS.

From the load curves it is seen that a maximum amount of power is approximately eight hundred eighty amperes at 1200 volts, and we propose to eliminate the substation at Union, but at the same time increase the capacities of the other two stations by 300 K.W., by moving the present 300 K.W. rotary from Union to Garden Prairie, and installing a new 300 K.W. rotary at Gilberts. The plan is to operate two 600 volt machines in series, in each station, and thus produce a trolley potential of 1200 volts. The additional equipment necessary will be new standard railway switch boards for 1200 volt service, and new transformers for use with the new machine. The present transmission line is of a sufficient size to take care of this additional equipment.

In changing the voltage from 600 to 1200 volts and eliminating the substation at Union, it was found necessary to replace the present 500,000 circular mill feeder with a 400,000 circular mill feeder from Gilberts west to Mark's Siding, a distance of two and six tenths miles, also from Garden Prairie east to the Marengo shops, a distance of five and fourttenths miles. This was done because at these two points trains pass each other, and hence the severest drain on the feeder system takes place. The present trolley wire was found to be too small to obtain the required voltage regulation, and as it has been in place since the opening of the line in 1907 it was deemed advisable to replace it with No. 0000 grooved wire thereby allowing a minimum of 1100 volts at the car.

[illegible] UNIT.

[illegible] the [illegible],
a Westinghouse 100-A motor will be used.
Both of these will be used on each unit, and
arranged with receiving-type H.B. Brakes.
A change-over switch will be installed so as
to afford the use of all four motors in parallel
on 600 volts, and two groups connected in paral-
lel with their respective motors connected in
series on 1200 volts. This is done to allow
full speed on Hereford and Interurban Lines,
over which the cars operate. A dynamotor will
also be supplied to give current at 600 volts
to the air compressor, lights and control cir-
cuits, while running on the 1200 volt section.
On 600 volt section the current will be supplied
direct from the trolley wire. The wiring in the
car bodies will have to be remodeled to with-
stand the increased voltage and additions will
have to be made to take care of the above appart-
us.

In [illegible] we did not [illegible] that a [illegible] could be handled by the use of 1200 volt direct current systems. Many engineers have advocated the single phase alternating current system as the solution of heavy traffic problems, but due to the fact that the direct current equipment is more flexible and much lighter and can be dealt with more alternating current equipment, and as, in all cases investigated, the direct current system was found to be cheaper than the corresponding alternating current system. Then, as this was previously a 600 volt direct current system, the trolley voltage could be raised with a minimum expense.

We believe that these expenditures would be more than offset by the increased profits in the ensuing years. We also wish to add that the reason why limited service was not included in our schedule was because the class of people did not warrant it, and the time saved was not great.

Any amount of light service can be added and additional constructed without any addition to the [illegible].